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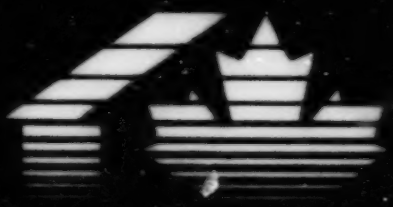

Variable Air Volume Retrofit of Office Air Handling Systems

A RESEARCH REPORT

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Variable Air Volume Retrofit of Office Air Handling Systems

A RESEARCH REPORT

A Review of Technical Requirements and Economics of Conservation of Constant Volume Office Air Handling Systems to Variable Air Volume Systems

Sponsored by the
Energy Conservation and Oil Substitution Branch
Energy, Mines and Resources Canada

Prepared by
Energy Systems Centre
Engineering Sciences Division
Ontario Research Foundation

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ABSTRACT/RESUME

This study examines the viability of variable air volume (VAV) system retrofits for constant volume air distribution systems with reheat. The aspects considered are fan capacity controls, building static pressure regulation, minimum outside air supply, adequacy of existing ductwork and terminal unit operation. Potential problems with low air movement are identified. Recommendations to examine alternatives to VAV are given.

* * *

La présente étude porte sur la possibilité de convertir un système de climatisation de débit continu avec recyclage de l'air de refroidissement inutilisé en un système de débit variable. On y examine, plus précisément, le réglage de la puissance du ventilateur et la régulation de la pression statique dans l'immeuble en cause, l'apport minimal d'air extérieur qui est requis, la convenance des canalisations en place et le fonctionnement de l'ensemble terminal. Le rapport fait état des difficultés que peut entrainer une circulation d'air insuffisante et des solutions qu'il est recommandé d'envisager avant d'installer un système de débit variable.

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This report was prepared by the Ontario Research Foundation. The sponsoring agency was Energy, Mines and Resources Canada, through the Building Energy Technology Transfer (BETT) Program.

The aim of the BETT Program is to promote widespread adoption of energy conservation in buildings by providing the necessary technological know-how and effecting its delivery to the appropriate end-users.

This report describes the technology for and economies of converting constant volume office air handling systems to variable air volume (VAV) systems. It is intended to provide HVAC contractors and designers and building owners/operators with an introduction to the potential possibilities of converting constant volume systems to VAV for energy savings. The report also contains warnings of potential problems that can be encountered, such as low air movement in office spaces.

A recent study carried out for the National Research Council supports these warnings and recommends that minimum airflow settings be set to provide sufficient air circulation and that supply air temperature be varied with space cooling loads to reduce reheat demands. Both of these recommendations are contained in this report.

Autrefois, beaucoup d'immeubles étaient équipés d'un système de climatisation de débit continu avec recyclage de l'air de refroidissement inutilisé. Bien que ces systèmes permettent de bien contrôler le milieu ambiant, le réchauffage de l'air inutilisé consomme souvent beaucoup d'énergie. On a donc commencé à installer des systèmes de débit variable pour diminuer la consommation d'énergie au réchauffage. Les installations qui se prêtent le mieux à la conversion à un débit variable sont l'ensemble terminal du système de débit continu à canalisation unique et recyclage et les systèmes de débit continu à double canalisation.

Au moment d'effectuer la conversion, il faut veiller à bien régler la puissance du ventilateur et la pression statique de l'immeuble, à assurer l'apport minimal requis d'air extérieur, à vérifier que les canalisations en place demeurent adéquates et à contrôler le fonctionnement de l'ensemble terminal et la diffusion de l'air dans les locaux, afin qu'il y ait toujours une bonne circulation d'air. Si l'on néglige l'un de ces aspects le rendement du système de débit variable ne sera vraisemblablement pas satisfaisant.

D'ailleurs, avant de convertir un système de débit continu, il faudrait d'abord envisager d'y apporter certaines modifications. Ainsi, on pourrait le mettre hors circuit pendant les périodes où l'immeuble est inoccupé, le rééquilibrer ou en modifier les commandes en rajustant la température de l'air d'apport en fonction de la superficie des locaux.

Dans la plupart des immeubles où l'on a procédé à la conversion, le système donne habituellement un rendement satisfaisant, une fois qu'on a éliminé les difficultés qui ne manquent pas de se manifester après sa mise en place. Des ingénieurs-conseils spécialisés en chauffage-ventilation-climatisation (CVC) tiennent le système de débit variable pour une solution viable; toutefois, beaucoup l'évitent en raison des difficultés qu'il peut poser et des autres solutions qui existent.

On ne devrait jamais installer un système de débit variable sans avoir d'abord pesé soigneusement tous les facteurs susmentionnés et constaté que le système sera effectivement rentable.

Il semble d'ailleurs que cette technique d'économie d'énergie vaille surtout pour les immeubles dont le système CVC fonctionne à peu près constamment et où les canalisations en place peuvent être intégrées au nouveau système.

1. INTRODUCTION

A Variable Air Volume (VAV) system is an air conditioning distribution system in which the volume of cooling air supplied to a space is varied to meet changing load conditions. This system can provide significant energy savings compared to other distribution systems, such as those where cooling air is supplied at a constant volume, and reheated when cooling loads are less than maximum. Constant volume reheat systems are easy to control, simple in operation and provide good environmental control. However, their relatively high energy requirements make them costly to operate.

VAV systems have become popular for new buildings and are being considered as retrofits for existing buildings. This report is intended to provide a description of existing types of air handling systems including VAV, along with requirements for retrofitting to VAV systems, and the potential problems that may occur. Examples of costs and savings from retrofit to VAV are estimated and reported.

Information for this report was gathered from a number of sources, including VAV equipment manufacturers, central system manufacturers, HVAC system designers and building owners.

A list of the companies contacted and a copy of the letter questionnaire sent to them is included in Appendix A.

In general, air handling systems consist of one or more fans for moving air, cooling and heating coils for conditioning of the air, ductwork carrying air from the fans to the conditioned space and return, and terminal units for mixing of the air and diffusion into the conditioned space.

Air distribution systems in use today can be differentiated on the basis of design velocities and number of ducts used. The majority of systems are either low or high velocity and single or dual duct.

Table 1 shows a listing of the most common types of systems.

In many cases a single duct system supplies cooling air only, and heat must come from reheat coils, radiators, or fan coil units. In a dual duct system, both warm air and cool air are supplied from the central system for heating and cooling. The ratio of warm air to cool air is varied to meet the conditioning requirements of the space.

Low velocity systems require larger ducts than high velocity systems, but are generally quieter and require less fan energy. High velocity systems, due to higher duct static pressures, require stronger duct work and more complex terminal units.

TABLE 1 - Common HVAC Systems

Classification	System Description
Single Duct Low Velocity	Single Duct Constant Volume Reheat
	Single Duct Variable Volume
Single Duct High Velocity	Single Duct Constant Volume Reheat
	Single Duct Variable Volume
	Single Duct Induction
Dual Duct Low Velocity	Dual Duct Constant Volume
	Dual Duct Variable Volume
Dual Duct High Velocity	Dual Duct Constant Volume
	Dual Duct Variable Volume

A more detailed description of the most common systems is given in Appendix B.

The control of VAV systems involves two subsystems, the central distribution system and the terminal units.

The central distribution systems usually consist of supply and return fans, air cleaning devices, fresh air intake, exhausts, cooling and heating coils and distribution duct work.

The terminal units contain volume controls, flow regulators and diffusers, and may also have reheat coils.

3.1 Central System

The controls of the central system are used to carry out three basic functions.

1. to ensure that outside air quantities supplied to the space do not fall below minimum requirements.
2. to keep system pressures within the operating range requirements of the terminal units
3. to maintain the space under a positive pressure to reduce infiltration

3.1.1 Outside Air Control

With constant volume systems, it is possible to set equipment to maintain minimum outside air requirements because of the constant air flows. However, with a variable volume system, outside air flowrate may decrease when the system is operating at less than full capacity. The problem is to maintain the minimum outside air requirements at the lowest system operating flows. This should be done without the penalty of conditioning extra amounts of outside air at higher flowrates. To accomplish this

it is necessary to provide control of outside air intake.

This can be achieved by two different methods. The first involves sensing the flowrate of outside air and controlling intake dampers to ensure that sufficient outside air is supplied.

In systems that have been designed to use 100 percent outside air for free cooling, the minimum required flows may be 25 percent or less of the design flowrate. Since air flow measurement is usually accomplished by measurement of air velocities, the low velocities at minimum air flow require sensitive instrumentation. To avoid this, the fresh air dampers can be split into sections, which are sequenced according to the supply fan flow control. The system can then be calibrated to provide required outdoor air flows.

3.1.2 Supply Fan Control

The second method of outside air control is to co-ordinate the supply and return air fans so that a constant difference in flow rates is achieved. The outside air flow rate will be the excess in supply air flow over the return air flow.

The supply fan must be sized to deliver the maximum air flow requirements for the cooling system at peak loads. However, most of the time, the system operates at less than maximum load. If the supply fan flow is kept constant, then part of this flow must be by-passed around the terminal units, back to the return air. An example of this bypass arrangement is given in Section 3.2.2. In systems where the supply air volume is varied there are a number of ways to control the quantity of air delivered. In centrifugal fan systems, as terminal units shut down, the static pressure in the system

will rise. Even if there is no control on the fan, the capacity of the fan will be reduced due to its operation characteristics. The fan power requirements will also be reduced. However, the increase in static pressure in the ducts may possibly affect the operation of the terminal units, and may even cause the ducts to rupture.

For these reasons, it is desirable to have some other method to control the fan capacities. Since the flow and static pressure are directly related, the most common method of controlling the supply air flow is from duct static pressures. These static pressures should be kept to the minimum required for operation of the terminal units, in order to achieve the greatest energy savings.

The usual ways of controlling fan capacity are outlet dampers, inlet vanes and variable speed drives. The outlet dampers decrease the fan's capacity by raising the outlet static pressure. Inlet vanes are used to spin the incoming air in the same direction as the fan rotation. This metnod will require less fan input power than outlet dampers. An alternate, but more costly approach is to use a variable speed motor or drive to control the fan speed.

The static pressure in the ducts is monitored through a controller that is used to vary the damper or vane positions or motor speed. The location of the static pressure sensor is important. If it is too close to the fan outlet, the operation of the fan may be unstable. Also, under high load conditions, terminal units at the ends of duct runs may not receive adequate air flows. This can be avoided by placing the static sensor near the end of the duct runs. This will ensure that all units receive sufficient flows.

3.1.3 Space Pressure Control

In a building with a return fan system, high negative pressures may be produced between the inside and outside of the building unless the return fan capacity is varied in accordance with that of the supply fan. These negative pressures can lead to excessive air infiltration and can have detrimental effects on the operation of exhaust systems. The two basic control strategies that are used to regulate building static pressure are controlling the return air fan capacity by sensing building static pressure, or by co-ordinating the return and/or exhaust air flow with the supply fan flow.

The first involves use of a sensor to measure the difference between the inside and outside static pressures. The reference point for the outside pressure must be selected carefully to minimize wind and stack effects. The return fan is then controlled by the same methods used to control supply fans, as mentioned above.

The second method involves setting up of the return fan to operate at a lower flow rate than the supply fan and then controlling both fans together. This requires that both fans have similar operational curves. The intermittent operation of large exhaust fans will affect the building static pressure when this method is used.

3.2 Terminal Units

The two categories of VAV terminal units are low velocity and high velocity units. Low velocity systems have low duct velocities and low static pressures (usually less than 250 Pa). High velocity units have higher duct velocities and static pressures of 1000 Pa and above. The following are examples of the typical control strategies used on VAV terminal units.

3.2.1 Low Velocity Single Duct Throttling Type

A typical unit is shown in Figure 1.

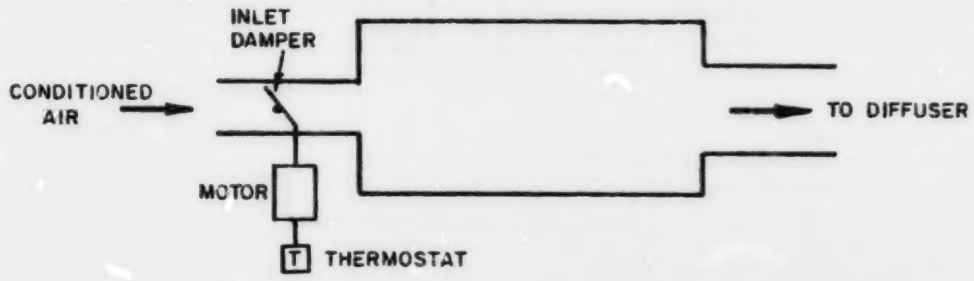

FIGURE 1. LOW VELOCITY SINGLE DUCT VARIABLE VOLUME SYSTEM

In this type of box, the position of the inlet damper is controlled by the thermostat. As the space temperature rises above the set point, the damper is opened. There are usually minimum and maximum volume settings, however the actual volume supplied will vary with the inlet static pressure of the system. For units in perimeter areas of buildings, reheat coils may be added for use in cold weather when the minimum volumes of air would overcool the space. These reheat coils are controlled in sequence with the damper, so that they only operate at minimum flow rate.

3.2.2 Low Velocity Single Duct Bypass Type

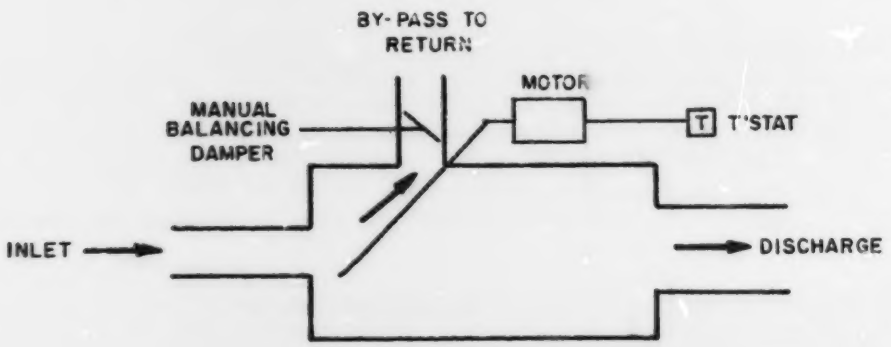

FIGURE 2. LOW VELOCITY SINGLE DUCT BYPASS TYPE UNIT

The unit varies the amount of air discharged to the space by controlling the position of a bypass damper in the terminal unit. This system requires a constant volume fan and thus does not gain any of the savings from reduced fan power usage.

3.2.3 High Velocity Single Duct Throttling Induction Box

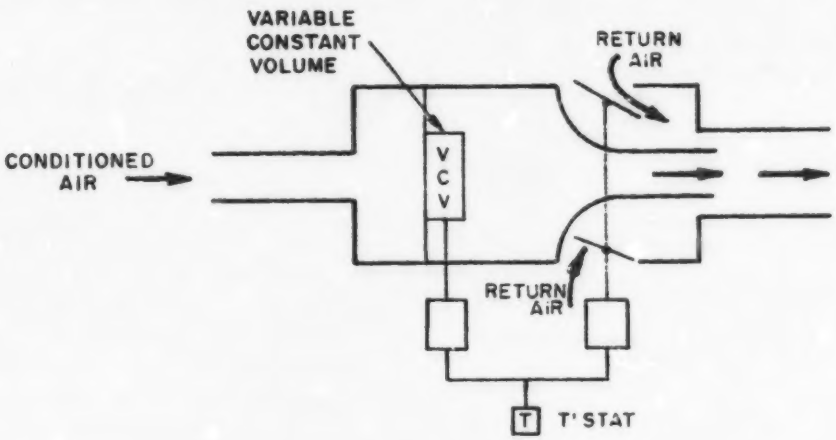

FIGURE 3. HIGH VELOCITY SINGLE DUCT THROTTLING INDUCTION BOX

In a constant volume high velocity system utilizing the throttling induction box shown in Figure 3, a constant volume flow is delivered to the space, however, the supply of conditioned air is varied according to the needs of the space. A constant volume control is normally used to maintain a constant flow rate to the conditioned space regardless of variations in duct static pressures. The set point of the volume controller is adjusted to vary the amount of cooling air supplied. At the same time the volume controller compensates for variations in the supply duct in the same way as a constant volume control. For this reason, the volume controller is often called a Variable Constant Volume (VCV) controller. The sequence of operation is such that at maximum cooling requirements the return air dampers are closed and the variable constant volume box is opened to maximum flow. As the temperature approaches the

thermostat set point, the cooling volume flow rate is reduced by adjusting the VCV controller. When heating is required, the cooling air volume is reduced and the return air dampers are opened.

3.2.4 High Velocity Single Duct Variable Constant Volume Throttling Type

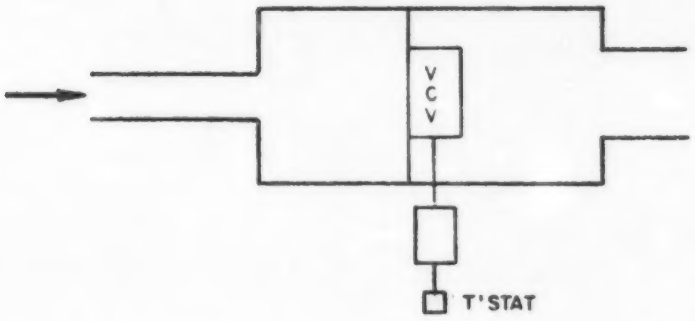

FIGURE 4. SINGLE DUCT VARIABLE CONSTANT VOLUME THROTTLING TYPE

In this unit the thermostat varies the setting of the constant volume regulator according to the space requirements.

3.2.5 High Velocity Single Duct Variable Constant Volume Bypass

This unit is similar to the low velocity type, with the addition of a constant volume regulator.

3.2.6 High Velocity Dual Duct Variable Constant Volume

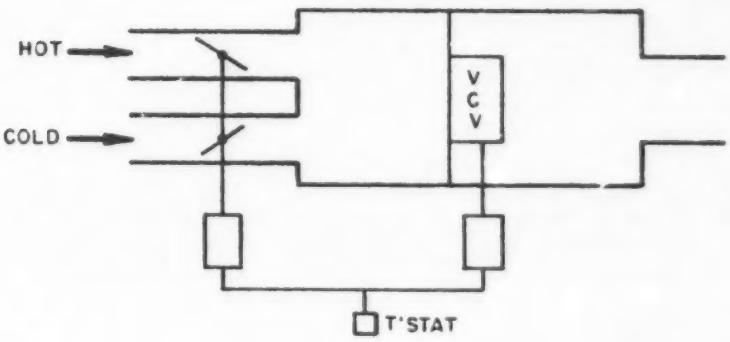

FIGURE 5. DUAL DUCT VARIABLE CONSTANT VOLUME

In this system the hot air damper and cold air damper are controlled by one actuator. Another actuator is used to adjust the variable constant volume box in the heating mode. During heating, the hot and cold supply dampers are varied to meet the heating needs of the space and the volume control is set at minimum flow. For cooling, the same control action takes place until the point where the cooling damper is fully open and the heating damper fully closed. If more cooling capacity is needed, the volume control box is then adjusted to increase the flow. Thus the variable flow occurs in the cooling mode only.

3.2.7 High Velocity Dual Duct, Dual Variable Constant Volume

The physical layout of this unit is similar to that shown in Figure 4. With this unit, however, an additional control feature is added to allow variation of volumes for both heating and cooling.

Variable Air Volume systems have the potential of reducing reheat and fan energy requirements as compared to constant volume single and dual duct systems. For this reason conversion of constant volume systems to variable volume has been considered as an energy conservation retrofit.

Some systems have been converted and, after correction of initial problems, have operated reasonably well. The success of retrofitting appears to depend on the selection of suitable retrofit equipment and the proper application and installation of this equipment.

In discussions with consultants and manufacturers, it was indicated that in general, it is best only to consider high velocity systems for retrofit to VAV. This is due to the fact that with VAV, the static pressure in the supply ducts will vary considerably within the ductwork in many locations. The high pressures possible with VAV could damage low pressure ducting, therefore reinforcing of duct work would be required. Also, changing static pressures at terminal units will result in changing flow rates since low velocity systems usually do not have constant volume controls. Therefore, the systems which are most commonly considered for retrofit are high velocity single duct constant volume reheat and high velocity dual duct constant volume systems. Assuming the existing duct work is suitable for the pressures in VAV systems, retrofit involves modification to the fan units and the terminal units.

4.1 Retrofit for Fan Units

According to the manufacturers, the supply and return must be modified to act as described in Section 3.1. It is generally possible to modify the existing fans for variable volume operation. Inlet vanes should be added to the fans for capacity control. If this is not possible, dampers can be used, however fan power savings will not be as great. A more energy efficient but more costly control is a variable speed drive for each fan.

The controls for these systems must be designed to meet the requirements outlined in Section 3.1. on Central System Control. Care must be taken to ensure that minimum outside air requirements are met with the new system.

4.2 Retrofit of Terminal Units

The terminal units to be considered for retrofit are those used on high velocity single duct constant volume reheat and high velocity dual duct constant volume systems. These are described below.

4.2.1 Retrofit of Single Duct Units

The two types of single duct variable volume systems in use are the throttling type described in Section 3.2.4. and the by-pass type described in Section 3.2.5. Since the fan flow remains constant for the by-pass type, the only change required is in the terminal unit. The existing unit must be replaced with one similar to that described in Section 3.2.5. The only savings resulting from retrofitting of this system will be a reduction in reheat requirements. Fan energy requirements are not affected.

Retrofitting to a throttling type VAV system can be done in many ways. An inlet damper can be installed on the box and modulated by the thermostat, as shown in Figure 6.

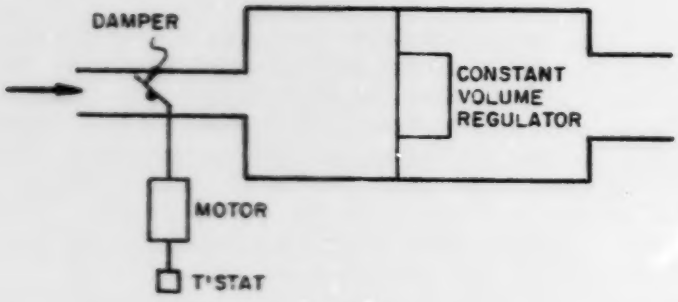

FIGURE 6. SINGLE DUCT VARIABLE VOLUME BOX

This system will provide poor control at higher flow rates, since the constant volume regulator will counter the control effect and act to maintain constant flow through the box. The system will only control when the air flow is below the minimum range of the constant volume regulator.

If the constant volume regulator is removed, the flow will be dependent on the inlet duct static pressures. This problem can be corrected by installation of a velocity sensor/controller to maintain constant flows. The controller is reset by the thermostat to give the variation in flows as required.

As an alternative, a new terminal box which provides variable constant volume control can be used. These units are available from VAV manufacturers.

One of the problems encountered with VAV systems is complaints about low air movement in the conditioned space. These complaints can generally be avoided by maintaining a minimum flow of not less than about 40% of maximum, and by using diffusers which entrain and mix room air to maintain air movement at lower flow rates. The cooling provided may exceed that required even with minimum air volumes and reheat may be needed.

4.2.2 Retrofit of Dual Duct Units

The most common type of constant volume dual duct unit in use is the dual duct mechanical constant volume unit as shown in Figure 7.

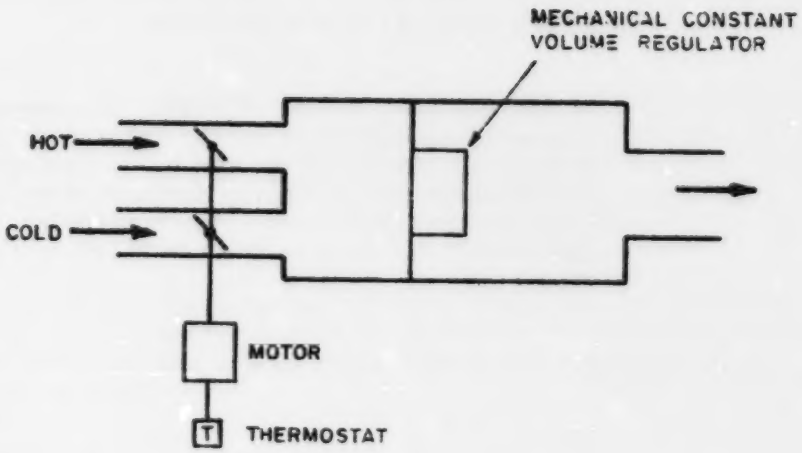

FIGURE 7. DUAL DUCT CONSTANT VOLUME UNIT

For interior spaces, it is often possible to cap the hot air supply completely and convert the unit to a single duct system. This retrofit then becomes similar to that described in Section 4.2.1.

For perimeter spaces where heating will still be required, the unit can be converted to a dual duct variable volume system. The recommended type of system is the dual duct dual variable volume unit described in Section 3.2.7. For this system the mechanical constant volume regulator must be replaced with a variable constant volume regulator. The same considerations of minimum air flow and air movement must be dealt with for this unit.

Variable Air Volume systems exhibit savings over constant volume systems in two areas:

1. reduced fan energy requirements
2. reduced reheat required

Estimates of the potential savings for these two features are presented below.

5.1. Fan Energy Savings

Peak cooling and heating loads are experienced for only a small portion of the year. A constant volume system is designed to supply the air volume requirements for maximum load regardless of load. A variable volume system is designed to provide air volumes required for maximum loads and to use reduced flows at lower loads.

Due to the varying nature of sun loads, all sections of a building do not experience their maximum cooling loads at the same time. While a constant volume system must be designed to meet all maximums, a variable volume system will follow the load, thus reducing the peak system design. Typically the peak capacity requirements of the VAV system will be about 80% of the requirement of a constant volume system for the same building.

Thus, in a new installation, or for a retrofit where the fans must be replaced, a smaller fan can be used for a VAV system than for a constant volume system.

The overall annual reduction in volume requirements from a constant volume system to a variable volume system is typically 30 to 40% [9]. This will result in a reduction of fan power requirements from 15% for outlet dampered systems to about 50% for systems with variable speed motors. For a typical inlet vane system the savings in fan power would be about 40%.

The annual energy savings can be estimated using the operating power of the fan and the length of operation as follows.

Power savings = Fan operating power x % reduction in power x operating hours/week x operating weeks per year.

For a fan with an original requirement of 1 kW for constant volume, operating 55 hours per week, 52 weeks per year the energy savings per year with a VAV system would be:

Savings = 1 kW x 40/100 power reduction, x 55 hours/week x 52 weeks/ year.

Energy savings = 1144 kWh per year.

For a system operating at a pressure of 1 kPa, the fan power requirements of a centrifugal fan are about 1.7 Watts/litre/sec.[13]

If we assume a building requirement of 3.77 L/sec/sq. meter (based on Public Works Canada recommendations), the fan power requirements for a building would be 6.4 Watts/sq.meter

Thus for a 10,000 sq. meter office building, the requirements for a constant volume system would be 64 kW. The savings for a VAV system would then be about 73,200 kWh per year, or about 7.32 kWh/sq.meter. According to Ontario Hydro, the average annual energy use for office buildings in Toronto is 470 kWh/year/square metre. Thus, the VAV savings would represent almost a 1.6% overall reduction in energy use.

5.2. Reheat Energy Savings

The energy savings for reheat of air in the variable volume system compared to the constant volume system will depend on the size of the flow reduction and the temperature difference between the supply and room air.

The heating savings will be:

Heat savings = Reduction in air flow (%) x air volume x (room temperature-supply air temperature) x specific heat of air x density x operating time.

If we assume a 30% reduction in air flow with VAV [9] for a 100 L/sec system operating 55 hours per week, 52 weeks per year, with a cold air temperature of 15 C and a room temperature of 21 C, the energy savings would be:

Energy saving = 30/100 x 100 L/sec x (21-15)Cx 1025 joules/kg-C x 0.0012 kg/L x 55 hours/week x 52 weeks/year.

Energy Savings = 633 kWh per year for 100 L/sec flow.

Thus for a 10,000 sq. meter office building with a design flow rate of 3770 L/sec, the energy savings would be 238,640 kWh per year, or about 23.9 kWh per square meter.

Based on the average annual usage of 470 kWh per square meter for Toronto office buildings, this would represent almost a 5% reduction in total energy use.

If the system were operating 168 hours per week instead of 55, the savings would be about 73 kWh per square meter per year, or about 16% of the total energy use.

There have been a number of buildings in Canada where constant volume systems have been retrofitted to VAV, however there is little information available on the actual savings resulting from these retrofits. Often, a number of other changes were carried out at the same time. Therefore, it is difficult to determine what energy savings resulted from the VAV retrofits.

The following are a few examples of case studies available for buildings in the U.S. and Canada.

6.1 Case 1: University of Western Ontario, London, Ontario.

In two buildings on the University campus constant volume reheat systems were retrofitted to VAV. Air was being supplied at 13 C in the University Community Centre and Social Science Building and reheated as necessary.

As part of the retrofit, variable inlet vanes were installed on the supply fans and outlet dampers were installed on return air fans. Constant volume regulators in the terminal units were replaced with variable volume regulators, with a minimum flow of nominally 40% of design maximum.

The estimated energy savings for this retrofit were 3,750,000 kWh of steam energy, combined with a 420,000 kWh reduction in chiller operation and a 1,730,000 kWh savings in reduced fan operation per year. The total cost for conversion was $210,000. (1977 $) and energy savings during 1977 amounted to nominally $120,000 resulting in a payback period of less than 2 years.

6.2 Case 2 - Brock University Thistle Complex Building

In the Thistle Complex building at Brock University's St. Catharines Campus, a dual duct air handling system was converted to variable air volume operation. Computer studies indicated that this conversion would result in a two year payback on the $60,000 conversion cost. Actual operating data gathered for two years following the changes showed savings to be close to the predictions.

No further details were available at the time of writing.

6.3 Case 3 - Office Building, Oklahoma City

A 16,000 square metre office building in Oklahoma City was converted from a constant volume terminal reheat system to a variable volume reheat system. The cost for this conversion in 1978 was $145,262. The estimated energy savings per year were 3,660,000 kWh or almost 230 kWh per square meter per year. The estimated pay-back period was just under 6 years.

6.4 Case 4 - Office Building, Austin, Texas

A 9,000 square metre office building in Austin, Texas was converted from a dual duct constant volume operation to a dual duct variable volume system. The cost for this conversion in 1978 was $53,065. The estimated savings were 2,240,000 kWh, or almost 250 kWh per square meter per year. The estimated pay-back period was less than 4 years.

Variable air volume systems do offer savings in energy compared to constant volume reheat systems. However, there are a number of points to take into account when a conversion is being considered. These areas are presented below.

7.1 Changes to Mechanical Systems

The existing fans, duct work, terminal units and diffusers require examination to determine what changes are required to accommodate a VAV system. A simple retrofit would consist of adding inlet vanes and/or dampers to supply and return fans and modifying terminal units for VAV operation. This type of retrofit would normally have the lowest capital cost.

If more changes to the system are required, the retrofit would become more costly. For example, new terminal units and diffusers may be required for many systems to have proper operation and good air movement. Some fans are not suitable for inlet vanes or dampers and new fans may be required. Finally, the existing duct work might not be capable of withstanding the static pressure forces created by the VAV system. Obviously, the simpler the change made, the more cost effective a particular retrofit will be, however the system must be properly designed for VAV operation to give acceptable space conditions.

7.2 Operating Time of System

The operating time of the air handling system will have a significant influence on the savings resulting from VAV retrofit. For fan systems savings, the savings will be proportional to the number of hours of operation per year.

The energy savings from reheat reduction are not as simple to estimate. The amount of reheat needed depends on the heat load of the space. For example, if lighting and people loads are reduced at night, greater reheat energy would be required for a constant volume system, whereas a VAV system would reduce the air supply.

If converting from a 24 hours per day, 7 days per week operation of a constant volume system, to a 55 hours per week operation of VAV system, the additional savings from reduced operating hours should not be attributed to savings from the VAV system since a simple time clock control can be used on the constant volume system to achieve this saving.

7.3 Control System Changes

Many constant volume reheat systems are set to supply 13 C cooling air all year round, no matter what the space requirements are. In most cases, this could be raised in the winter time to 16 C or even 18 C without major operational changes. This would greatly reduce the reheat requirements for the system. Again, the energy savings possible from fairly simple control system changes should be considered as an alternative to VAV retrofit. While many people believe that VAV systems will eliminate reheat completely, this is not usually true. In most cases, a minimum volume of 40% of design must be maintained. For exterior zones in the heating

season, reheat will be required unless solar loads are high. The amount of reheat required will be dependent on the supply air temperatures.

When a building owner is considering changing a constant volume system to a VAV system, he should first investigate low cost energy conservation measures. These measures include shutdown of HVAC systems during unoccupied periods, control of supply air temperature to reduce reheat or balancing of distribution systems. Once the possible savings from these measures have been determined, the incremental benefit from converting to VAV should be calculated.

When these points are taken into account, it will be found that the best candidates for VAV retrofit are those offices where air conditioning systems must operate at all times and existing fans and duct work can be used in the new VAV system. It is important to ensure that VAV systems are designed properly to provide minimum outside air requirements, adequate building static controls and good air distribution in the office space. Failure to meet one of these requirements will result in a system that, although saving energy, will probably be condemned by building occupants and may result in reduced work productivity.

Further information on VAV systems can be obtained from the publications listed in the bibliography.

Information on retrofitting of Variable Air Volume systems is available from manufacturers of this equipment. Most manufacturers have computer programs for estimating costs and energy savings from VAV retrofits for specific buildings.

From the limited number of cases available, it appears that costs for conversion of constant volume systems to VAV are in the order of $10.00 per square meter of floor area. Simple conservative calculations show that annual savings with VAV would be in the area of 30 to 130 kWh per square meter, depending on operating hours and airflow reductions. At a cost of $.03 per kWh this would represent a saving of $.90 to $3.90 per square meter, suggesting payback periods ranging from 2.6 to 11 years. The shortest paybacks would be for offices where systems run all of the time and average airflow reduction of about 40% could be achieved. Application of low cost measures such as shutdown in unoccupied periods and supply air temperature reset will reduce the residual benefits from VAV.

The case studies available indicate that VAV retrofits have paybacks of two years or greater.

Consultants who have been involved in VAV retrofit projects feel that they are viable if problems encountered after retrofit have been solved.

Information on the number of buildings with a potential for retrofit to VAV was not available. It is recommended that the effectiveness of low cost measures to reduce reheat and fan energy use be investigated. Alternate methods to VAV retrofit should be studied to determine the actual energy savings and costs associated with these alternatives.

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LETTER AND SURVEY QUESTIONNAIRE

ONTARIO RESEARCH FOUNDATION

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January 29, 1982

Dear Sir:

Until fairly recently, it was common practice in most office air conditioning systems to use constant volume supply systems with reheat. This is a wasteful process, since energy is often required for coding of the air, and again for reheating of the air. An alternative design which has already been adopted for most new buildings is the variable air volume (VAV) systems. However, the greatest potential for energy conservation lies in the retrofit of existing buildings using reheat systems.

In order for building owners to assess the feasibility of installing VAV systems, it is necessary to know the actual costs associated with their retrofit and the resulting energy savings. As part of the Building Technology Support Program sponsored by Energy Mines and Resources Canada, the Ontario Research Foundation is conducting a survey of consulting engineers to identify buildings where constant volume systems have been replaced with VAV systems. "Our objective is to determine the economic feasibility and provide a technical information package on VAV retrofit systems for owners and consultant.

We would appreciate receiving your replies to the attached questionnaire along with any information that you have available regarding

- energy savings
- retrofit costs
- specific buildings where VAV systems have been retrofitted.

We wish to thank you in advance for your cooperation in this study. If you have any questions regarding this survey please feel free to contact myself, Mr. Colin McGugan at 416-822-4111.

Yours truly,

John Liou
Assistant Research Scientist
Department of Engineering & Metallurgy

SURVEY QUESTIONNAIRE - RETURN TO ORF

Company Name:

Contact:

Address:

1. Have you converted any office building systems from constant air volume to variable air volume?

   YES _____
   NO _____

   If yes - how many? _____

2. Are you designing any VAV systems for retrofit in the near future?

   YES _____
   NO _____

3. Do you have data on energy use before and after retrofit?

   YES _____
   NO _____

4. Do you have retrofit costs available?

   YES _____
   NO _____

5. Would you be willing to provide this information to ORF for use in case studies?

   YES _____
   NO _____

6. Do you feel that VAV retrofit is a cost effective measure?

   YES _____
   NO _____

DESCRIPTION OF AIR DISTRIBUTION SYSTEMS

DESCRIPTION OF AIR DISTRIBUTION SYSTEMS

B.1 Dual Duct Constant Volume

A schematic of this type of system is shown in Figure B-1. The supply air is divided into two duct systems (dual ducts). One stream is heated and the other cooled. The two systems are routed around the building together. Each space is supplied by at least one terminal unit with a mixing box. The flow from each duct is controlled according to the heating or cooling requirements of the space. As more heating is required, cooling air volume is cut back and heating air volume is increased. The opposite occurs if more cooling is required.

The hot and cold streams are mixed together and discharged to the space through a diffuser. The air flow from the diffuser remains approximately constant for this type of system.

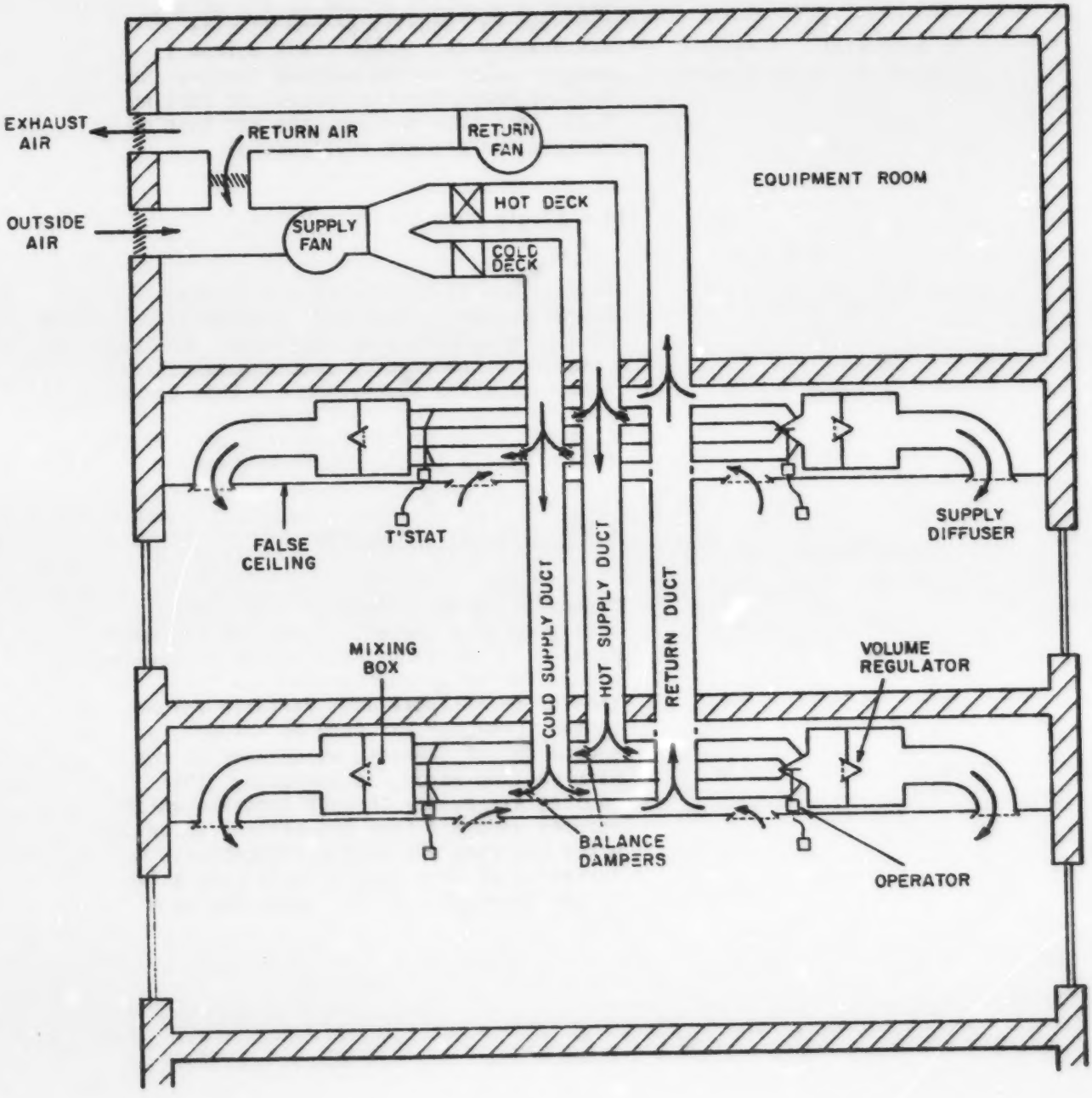
B.2 Dual Duct Variable Volume

A dual duct variable volume system is similar to the system shown in Figure B.1. The main difference between this system and a constant volume system is the terminal units, which are designed to allow changes in volume. There are various control strategies for this type of system. Basically there are two operations, a volume control and a mixing control.

The mixing control varies the ratio of the cooling air flow and the heating air flow as in the constant volume dual duct system. The volume control is used to vary the volume of air. In one type of system, variation is done in the cooling mode only. At maximum cooling requirements the volume controller is set to maximum flow. As the cooling level decreases, the flow is decreased until a minimum flow set point is reached. At this point, the mixing control takes over and blends the cold and hot air to meet the space requirements.

A variation of this system uses a control which also increases the hot flow as the heating load increases.

FIGURE B-1 - DUAL DUCT AIR DISTRIBUTION SYSTEM



B.3 Single Duct Constant Volume Reheat

A typical single duct constant volume reheat is illustrated in Figure B.2. In this system a constant volume of air at one temperature, usually around 13 C is supplied to the space. This volume is usually based on the maximum cooling and heating loads for the space. At cooling loads less than maximum, the air must be reheated to prevent overcooling.

B.4 Single Duct Variable Volume

This system is similar to the constant volume system, except that instead of reheating at part load conditions, cooling capacity is reduced by cutting down the air volume supplied to the space. This can be done by throttling the air flow at the terminal unit, or by by-passing part of the flow directly to the return systems.

B.5 Single Duct Induction

Figure B-3 shows a schematic of a single duct induction system. There are two main types. In the first, the volume of cooling air is varied by the terminal units, similar to a single duct variable volume system. However, at reduced volumes, a second set of dampers, which open to the warm ceiling space, is operated. The cooling air passes through a nozzle which induces warm air from the ceiling space and mixes the warm and cold air together. A variation of this type of unit uses a fan in the terminal unit to induce the warm air.

The second type of induction unit has a constant flow of cold air through the induction nozzles. The unit can induce air either from the warm return air plenum, or from the conditioned room, which will have a lower temperature than the return air plenum, depending on the cooling requirements of the space. This type of system has a constant supply and return flow.

FIGURE B-2 SINGLE DUCT AIR DISTRIBUTION SYSTEM

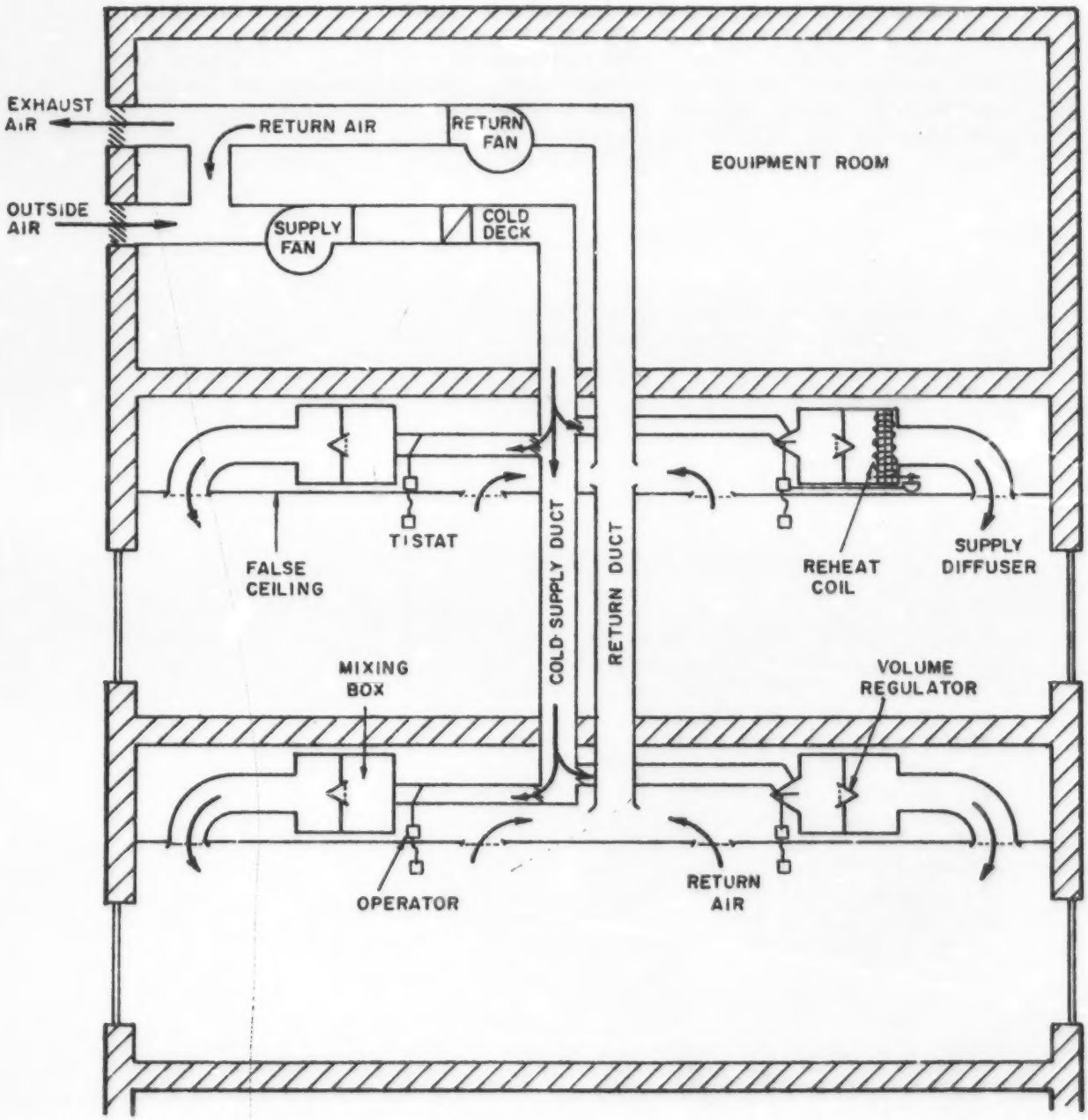


FIGURE B-3 INDUCTION AIR DISTRIBUTION SYSTEM